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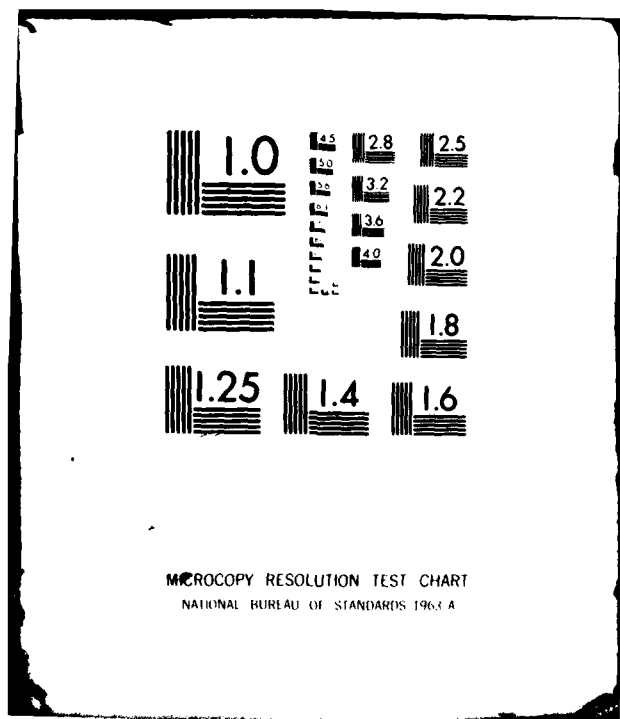
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LOW ENERGY ATOMIC COLLISIONS

Final Scientific Report  
for Period 1 October 1977 - 30 April 1980

Contract Number: F49620-78-C-0015

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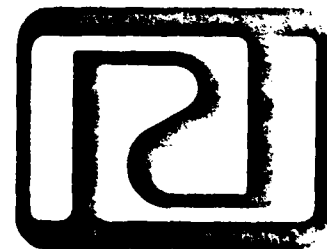
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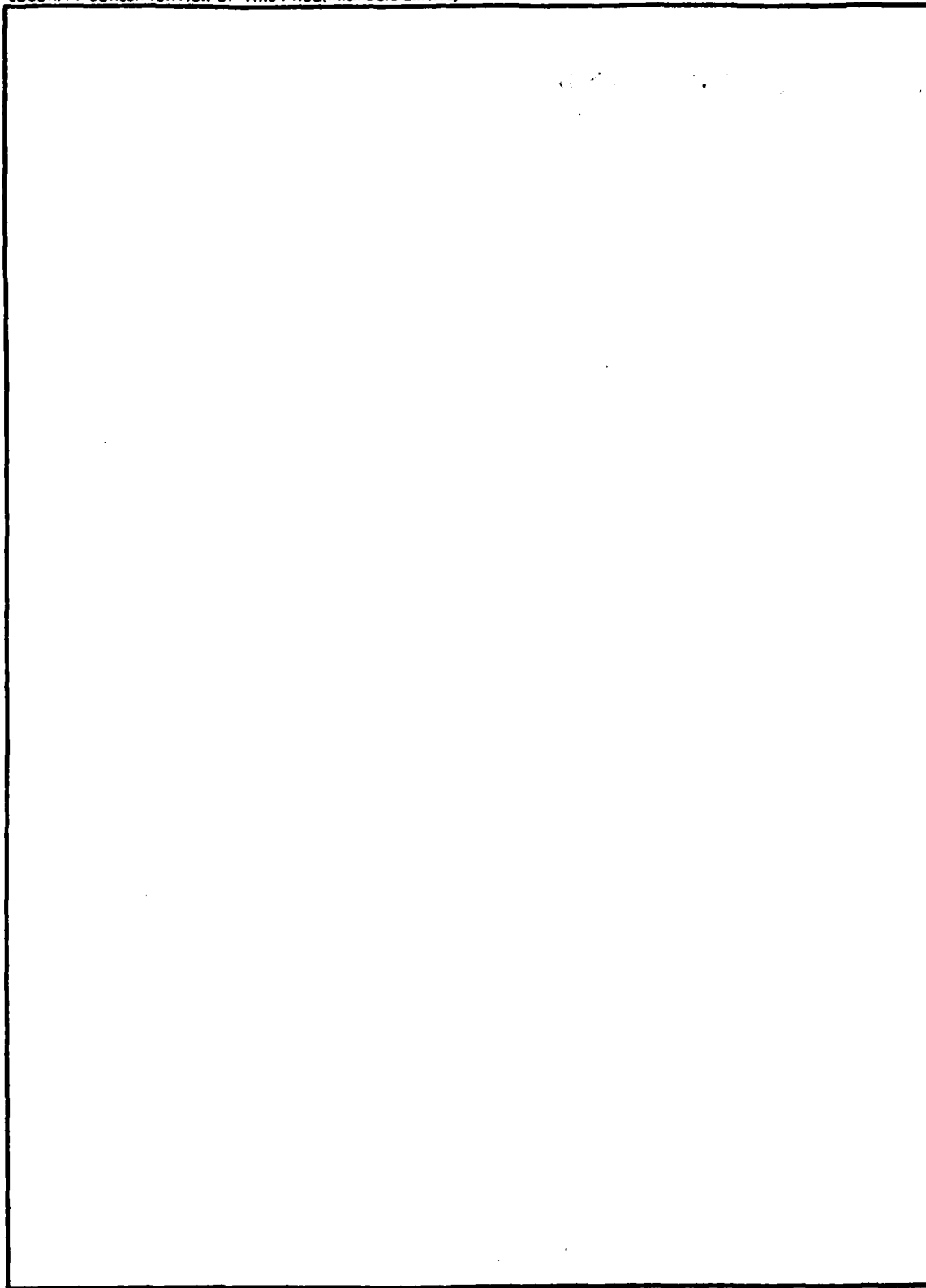
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A summary of research performed under AFOSR Contract No. F49620-78-C-0015 is given. The contract covered the period 1 October 1977 - 30 April 1980. The report describes merging-beams studies of chemi-ionization and/or ion-molecule reactions. Included are investigations of the He*-D, Ne*-Xe, He*-He*, Ar*-Kr*, Ne*-Ar*, He*-Ne*, and He*-Ne* systems.			

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The goal of this experimental program was to study selected chemi-ionization and ion-molecule reactions by merging-beams techniques to better understand the dynamics of such collisions and to provide data to assist in the formulation of theory. The relative energy of the reactants for these studies was varied from threshold to 10 or 20 eV.

These studies give a clearer picture of the role played by the kinetic and internal energy of reactants at low relative energies. This is important for the development of advanced Air Force systems that require communication through either a naturally or artificially ionized atmosphere, for the development of propulsion systems for the Air Force, and for advancing the techniques of lasers.

#### ACCOMPLISHMENTS

During the contract period merging-beams studies were made of two chemi-ionization reactions involving rare-gas metastables  $A^*$  colliding with ground-state atoms B. These  $A^*-B$  systems are  $He^*-D$  and  $Ne^*-Xe$ . Cross sections  $Q$  were measured for both associative ionization AI ( $A^* + B \rightarrow AB^+ + e$ ) and Penning ionization PI ( $A^* + B \rightarrow A + B^+ + e$ ) over a range of  $W$  from 0.01 to 10 eV, where  $W$  is the relative energy of the collision. The total ionization cross section  $Q_T$  is defined as the sum of the PI and AI cross sections, i.e.,  $Q_T \equiv Q_{AI} + Q_{PI}$ . It was learned that the  $Q_T$  vs  $W$  curves and branching ratios  $R \equiv Q_{AI}/Q_T$  could be explained qualitatively by the so-called two state potential theory.<sup>1</sup> However, when the data for the  $He^*-D$  system were compared to theoretical results such as those of Hickman and Morgner,<sup>2</sup> it was found that quantitative agreement was not good at all  $W$  where comparisons could be made. This is most likely the result of using imprecise potentials in the theory. No theoretical results exist for the  $Ne^*-Xe$  system so comparisons could not be made.

During the contract we have also conducted chemi-ionization studies of reactions between two metastable rare gases  $A^*$  and  $C^*$ . These  $A^*-C^*$  systems were  $He^*-He^*$ ,  $Ar^*-Kr^*$ ,  $Ne^*-Ar^*$ , and  $He^*-Ne^*$ . The data are particularly useful since they afford some degree of predictability of cross sections for  $A^*-C^*$  systems in general, which have received very little theoretical attention.

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The data we have obtained for both  $A^*-B$  and  $A^*-C^*$  systems have also enabled us to determine potential well depths  $\epsilon^*$  of  $A^*B$  and  $A^*C^*$  molecules which have  $\epsilon^*$  greater than a couple of tenths of an electron volt. Our  $\epsilon^*$ 's agree well with those obtained by other methods when comparisons can be made. For  $A^*-C^*$  systems there are no measurements other than ours.

In addition to studying chemi-ionization reactions we obtained absolute and relative cross sections for the charge-transfer reaction  $He^+(1S) + Ne^* \rightarrow He^+ + Ne^+$ . The  $Ne^*$  represents a composite of  $Ne(3s\ ^3P_2)$  and  $Ne(3s\ ^3P_0)$ , and the  $He^+$  represents various excited states of He. The studies were made by a merging-beams technique for  $0.1 \leq W \leq 500$  eV. The data indicate that the reaction is directed with most of the product  $Ne^+$  scattered in the direction of the reactant  $Ne^*$ . The cross section monotonically increases with  $W$ . The threshold for the reaction is near 0.1 eV. A modified Demkov approach was used to calculate cross sections,<sup>3</sup> which agree very roughly with the experimental values above  $W \approx 3$  eV. At lower  $W$  the agreement is poor. This experiment is unusual because so few studies have been made of charge transfer involving excited reactants, and particularly in the generally inaccessible region of  $W$  that we have covered.

Finally, we have experimentally determined the composition of a partially metastable helium beam in the energy range 3500-4000 eV. The technique used has been described previously.<sup>4</sup> The helium beam was produced by charge transfer of  $He^+$  in Na vapor and contains metastable  $He(2^3S)$ ,  $He(2^1S)$  and ground state  $He(1^1S)$  atoms. We have also determined the composition of a partially metastable krypton beam generated by charge transfer of  $Kr^+$  at energies of 3500, 4500, and 5500 eV in Cs vapor. These measurements help us interpret our chemi-ionization experiments and are also useful to other researchers.

Much of the information discussed above was presented by R. H. Neynaber as an invited talk entitled "Merging-Beams Experiments with Excited Atoms." The talk was given at the XI International Conference on the Physics of Electronic and Atomic Collisions in Kyoto, Japan, 29 August-4 September 1979.

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## PAPERS AND TALKS

### Published Papers

1. R. H. Neynaber, G. D. Magnuson, and S. Y. Tang, "Chemi-ionization in Collisions of Metastable Helium with Metastable Helium," J. Chem. Phys. 68, 5112 (1978).
2. S. Y. Tang and R. H. Neynaber, "Charge Transfer Between Helium Ions and Metastable Neon," Phys. Rev. A18, 1925 (1978).
3. R. H. Neynaber and S. Y. Tang, "Penning and Associative Ionization in the Metastable Helium-Atomic Deuterium System," J. Chem. Phys. 69, 4851 (1978).
4. R. H. Neynaber and S. Y. Tang, "Chemi-ionization in Collisions of Metastable Neon with Xenon," J. Chem. Phys. 70, 4272 (1979).
5. R. H. Neynaber and S. Y. Tang, "Composition of Partially Metastable Kr Beams," Chem. Phys. Lett. 65, 150 (1979).
6. R. H. Neynaber and S. Y. Tang, "Chemi-ionization in Collisions of Metastable Argon with Metastable Krypton," J. Chem. Phys. 71, 3608 (1979).
7. R. H. Neynaber and S. Y. Tang, "Chemi-ionization in the Metastable Neon-Metastable Argon System," to be published in the May 15, 1980 issue of J. Chem. Phys.
8. R. H. Neynaber and S. Y. Tang, "Penning Ionization of Metastable Helium in the Metastable Helium-Metastable Neon System," to be published in the May 15, 1980 issue of J. Chem. Phys.

### Talks

1. R. H. Neynaber and S. Y. Tang, "Penning and Associative Ionization in Systems of Two Metastable Reactants," Thirtieth Annual Gaseous Electronics Conference, Palo Alto, California (1977).
2. R. H. Neynaber and S. Y. Tang, "Chemi-ionization in Collisions of Metastable Helium with Metastable Helium," Conference on Dynamics of Molecular Collisions, Asilomar, California (1978).
3. R. H. Neynaber and S. Y. Tang, "Penning and Associative Ionization in the Metastable Helium-Atomic Deuterium System," 10th Annual Meeting of the Division of Electron and Atomic Physics, Madison, Wisconsin (1978).

4. S. Y. Tang and R. H. Neynaber, "Penning and Associative Ionization in the Metastable Argon-Metastable Krypton System," XI International Conference on the Physics of Electronic and Atomic Collisions, Kyoto, Japan (1979).
5. R. H. Neynaber, Invited paper on "Merging-Beams Experiments with Excited Atoms," XI International Conference on the Physics of Electronic and Atomic Collisions, Kyoto, Japan (1979).
6. R. H. Neynaber and S. Y. Tang, "Chemi-ionization in the Metastable Neon-Metastable Argon System," 11th Annual Meeting of the Division of Electron and Atomic Physics, Houston, Texas (1979).

#### PERSONNEL

R. H. Neynaber and S. Y. Tang have conducted the research for this contract.

#### USE OF RESULTS

##### For Review Papers

The subject of chemi-ionization is of much interest lately. An understanding of chemi-ionization reactions is important for the further development of many areas including laser technology, combustion, high voltage switching, and commercial and residential lighting. Ion-molecule reactions are useful, for example, in understanding atmospheric, nuclear weapons, and fusion reactor effects.

##### By Other Experimentalists and Theoreticians in the Field

Our results are being used by experimentalists and theoreticians who are also engaged in research directed at understanding the dynamics of atomic and molecular collisions. These scientists include Prof. J. H. Futrell (Dept. of Chem., Univ. of Utah), Prof. F. W. Lampe (Dept. of Chem., Pennsylvania State Univ.), Prof. N. F. Lane (Dept. of Physics, Rice Univ.), Drs. R. E. Olson and D. C. Lorents (SRI International), Prof. W. H. Miller (Dept. of Chem., Univ. of Calif. at Berkeley), Prof. J. C. Polanyi (Dept. of Chem., Univ. of Toronto), and Dr. A. V. Phelps (JILA).

L. Champagne of the Naval Research Laboratory is interested in our chemi-ionization research as it applies to lasers. One purpose for our studying the  $\text{Ne}^+ - \text{Xe}$  system is that it is directly related to the development of a high power Xe-F laser. The working gas of such a laser is a  $\text{Ne/Xe/F}_2$  mixture in which Ne, as a diluent, aids in excitation transfer. Chemi-ionization in the  $\text{Ne}^+ - \text{Xe}$  system is a loss mechanism for such transfer.

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1. For example, see (a) H. Hotop and A. Niehaus, Z. Phys. 238, 452 (1970); (b) H. Hotop, Radiat. Res. 59, 379 (1974).
2. A. P. Hickman and H. Morgner, J. Chem. Phys. 67, 5484 (1977).
3. See, for example, R. E. Olson, Phys. Rev. A6, 1822 (1972).
4. R. H. Neynaber and G. D. Magnuson, J. Chem. Phys. 65, 5239 (1976).